EVALUATION OF SEXUAL DIMORPHISM OF FORAMEN MAGNUM IN DRY HUMAN SKULLS

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Abstract

Introduction

The foramen magnum is a large opening in the base of skull, it is oval, wider behind with greatest diameter being antero-posterior. It contains the lower end of the medulla oblongata, the vertebral arteries and spinal accessory nerves. The dimensions of the foramen magnum are clinically important because the above mentioned vital structures passing through it may endure compression such as in cases of foramen magnum herniation, foramen magnum meningiomas and foramen magnum achondroplasia.

Materials and Methods

This is a prospective and observational study conducted in the Department of Anatomy, Index Medical College. Maximum anteroposterior diameter of the Foramen Magnum: Maximum distance between anterior and posterior margins measured along the midsagittal plane of the Foramen Magnum. Maximum transverse diameter of the Foramen Magnum: Maximum distance between the lateral margins measured along the transverse plane of the Foramen Magnum. Length of the occipital condyle: Maximum length of the Occipital Condyle taken along the articular surface and the parameter is recorded bilaterally. Maximum width of the occipital condyle: Maximum width of the Occipital Condyle taken along the articular surface perpendicular to the Occipital Condyle length and the parameter is recorded bilaterally

Results

100 subjects were studied (80 males and 20 females) with an overall mean age of 38.92 ± 10.95 years. The mean and standard deviation for all the five measurements were obtained to derive the FM dimensions in the study population, which showed that except LD all other parameters were noted higher in males, highlighting sexual dimorphism in FM dimensions. Gender accuracy formula: [(-0.263 x LD) +0.156 x TD) + (0.437 x C) + (0.659 x A)] – 102.17 By applying the data to the derived equation, canonical variables were derived for all the parameters of FM dimensions. Also, an attempt was made to assess the efficiency of all

five parameters of FM in sex determination. The overall accuracy of 72.5% was got when 120 subjects were considered. The maximum accuracy was got for C and the least for LD.

Conclusion
The study recommends the use of SMV radiographs in elucidating FM morphometric variations for the identification of unknown individuals and may act as a guide to the anatomists, neurosurgeons, and in other medical fields as well. These findings would be interrogated as reliable indicators in sex determination of unknown skulls. Data should be only used as a corroborative finding in predicting sex in case of fragmented cranial bases and not recommended as sole indicators for sexing complete skulls.

Keywords: Foramen Magnum, Dry Human Skulls, Occipital Bone.

Introduction

The foramen magnum is a large opening in the base of skull, it is oval, wider behind with greatest diameter being antero-posterior. It contains the lower end of the medulla oblongata, the vertebral arteries and spinal accessory nerves [1]. The dimensions of the foramen magnum are clinically important because the above mentioned vital structures passing through it may endure compression such as in cases of foramen magnum herniation, foramen magnum meningiomas and foramen magnum achondroplasia [2]. The knowledge of foramen magnum diameters is needed to determine some malformations such as Arnold Chiari syndrome, which shows expansion of transverse diameter [3].

The dimensions of the foramen magnum are important prior to the cutting off of the foramen magnum lesions or posterior cranial fossa lesions, because more the antero-posterior diameter, greater is the contra lateral exposure [2]. The diameters and area of the foramen magnum are greater in males than in females, hence its dimensions can be used to determine sex in the medicolegal conditions, especially in the following circumstances, such as explosions, aircraft accidents and war fare injuries [3,4]. Foramen magnum is about 3cm wide by 3.5cm anteroposteriorly [5, 6]. It is located midway between and on a level with mastoid processes.22 The foramen magnum is surrounded by different parts of the occipital bone, squamous part lies behind and above, basilar part in front and a condylar part on either sides [7,8].

On each side its antero-lateral margin is encroached by occipital condyles, hence the foramen magnum is narrow anteriorly. The anterior edge of the foramen magnum is slightly thickened and lies between the anterior ends of the condyles. The posterior half of the foramen magnum is thin and semicircular. Upper ends of anterior and posterior atlanto-occipital membranes are attached to the anterior and posterior margins of the foramen magnum respectively, and their lower ends are attached to the superior surface of anterior and posterior arches of the atlas respectively. [6]

The foramen magnum is a wide communication between posterior cranial fossa and the vertebral canal. The narrow anterior part of the foramen magnum has apical ligament of dens,

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upper fasciculus of the cruciate ligament and membrana tectoria, both are attached to the upper surface of basioccipital bone infront of the foramen magnum. Its wide posterior part contains the medulla oblongata and its meninges. In subarachnoid space spinal rami of the accessory nerve and vertebral arteries, with their sympathetic plexus, ascend into the cranium; the posterior spinal arteries descend posterolateral to the brain stem, where as anterior spinal artery descends anteromedian to the brain stem. The cerebellar tonsils may project into the foramen magnum [9].

The fitted nonachondroplastic foramen magnum growth curves demonstrate that the maximum growth occurs in the first 18 months and slows thereafter. Indeed, the sagittal dimension almost doubles within the first 2 years, while the transverse dimension enlarges by half the original dimension. Growth of this area is essentially complete by 5 years. The achondroplastic foramen magnum is small at birth, and during the first year it has a very severely impaired rate of growth essentially in the transverse dimension. This markedly diminished growth results not only from abnormal enchondral bone growth but also because of abnormal placement and fusion of the synchondroses [10].

Materials and Methods

This is a prospective and observational study conducted in the Department of Anatomy, Index Medical College.

- Hundred human adult dry skulls of either sex.

- Digital Vernier Calipers.

- Flexible wire.

STUDY METHODS: Dry skull Method

SPECIMEN COLLECTION: Hundred human adult dry skulls of either sex.

A. DRY SKULL METHOD:

Inclusion criteria:

1. Adult human dry skull of either sex of 18-60 years .

2. Third molar tooth erupted.

3. Well defined skull sutures.

Exclusion criteria:

1. Abnormal skulls.

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2. Damaged skulls.

The measurements of parameters related to Foramen magnum and occipital condyle
1). Maximum AP diameter of the Foramen Magnum

2) Maximum transverse diameter of the Foramen Magnum

The following measurements will be made with the use of digital vernier calipers
1) Maximum anteroposterior diameter of the Foramen Magnum: Maximum distance between anterior and posterior margins measured along the midsagittal plane of the Foramen Magnum

2) Maximum transverse diameter of the Foramen Magnum: Maximum distance between the lateral margins measured along the transverse plane of the Foramen Magnum

Statistical analysis
Statistical analysis was performed using SPSS (Statistical Package for Social Sciences, version 25.0) computer software. Continuous variables were presented as mean ± SD (standard deviation). The two groups were compared with student-t test while paired t-test was used to compare paired groups.

Results

100 subjects were studied (80 males and 20 females) with an overall mean age of 38.92 ± 10.95 years [Table 1]. The mean and standard deviation for all the five measurements were obtained to derive the FM dimensions in the study population, which showed that except LD all other parameters (TD, circumference, area, FI) were noted higher in males, highlighting sexual dimorphism in FM dimensions. To substantiate this, *P*‑value was calculated using Student's t‑test and it was seen that *P*‑value was <0.05 for TD, circumference, area, and FI suggesting statistically significant differences between the two genders [Table 2].

Table 1: Distribution of subjects among both genders

			Age	
Gender	***n***	**%**	**Mean**	**SD**
Male	80	80%	39.24	12.15
Female	20	20%	38.61	9.75
Total	100	100%	38.92	10.95

n: no of subjects, SD: standard deviation

Table 2: Sexual dimorphism in the foramen magnum dimensions among various parameters

Foramen magnum dimensions	Males		Females		*P*
	Mean	SD	Mean	SD	
Longitudinal diameter (LD)	36.93	2.86	36.3	3.21	0.99
Transverse diameter (TD)	33.52	2.52	31.12	2.84	0.006
Circumference	96.62	5.71	94.51	12.94	0.02
Area (mm2)	790.82	132.1	752.36	75.23	0.09
Foramen index	1.26	0.32	1.36	0.23	0.03

For evaluating inter‑observer agreement, correlation (*r* ‑value) was calculated for all the FM dimensions as measured by two observers. The *r*‑ value showed a strong correlation for all, suggesting good interobserver agreement. The interobserver agreement was found to be 85%.

Gender accuracy formula: [(‑0.263 x LD) +0.156 x TD) + (0.437 x C) + (0.659 x A)] – 102.17 By applying the data to the derived equation, canonical variables were derived for all the parameters of FM dimensions. Also, an attempt was made to assess the efficiency of all five parameters of FM in sex determination. The overall accuracy of 72.5% was got when 120 subjects were considered. The maximum accuracy was got for C and the least for LD.

The results for intra-observer variations are depicted in Table 3. The differences seen between the measurements recorded at two different occasions were found to be non-significant as is clear from the t- value. This observation also gets conformation from the highly correlated values of correlation co-efficient. Table 4 presents the descriptive statistics and t values for all the measured variables of the occipital bone. The results clearly indicate that males displayed larger mean values than females for all measured variables of the cranial base. However, statistically significant differences between the sexes ($p<0.05$) were observed only for a single measurement of maximum bicondylar breadth (BCB).

When values of coefficient of variations between sexes were compared it was found that females exhibited more variability than males for measurements like length of foramen magnum, width of foramen magnum, minimum distance between occipital condyles, maximum interior distance between occipital condyles and area of foramen magnum while, males were more variable for maximum bicondylar breadth and external hypoglossal canal distance**.** Discriminant function analysis for cranial base has been presented. It also shows the unstandardized coefficients, constants, and sectioning points that were used to formulate the discriminant function score equation. Only significantly dimorphic value (BCB) was entered into the stepwise discriminant function analysis and rest of the variables were subjected to direct analysis.

Table 3: Intra-observer variations assessment using paired t-test.

Variable	First observed mean	Second observed mean	SD	t- value	Correlation Coefficient
LFM	37.20	37.35	1.42	-0.92	.98
WFM	32.40	32.80	1.02	1.49	.97
BCB	54.60	53.80	2.34	1.26	.92
MnD	18.60	18.70	1.59	-0.40	.90
MxID	30.20	28.30	1.99	0.91	.93
EHC	39.70	37.10	3.28	1.50	.94

*LFM, maximum length of the foramen magnum; WFM, maximum width of the foramen magnum; BCB, maximum bicondylar breadth; MnD, minimum distance between occipital condyles; MxID, maximum interior distance between occipital condyles; EHC, external hypoglossal canal distance

†All measurements are in millimeters

Sex of the skull and fragmentary cranial remains can be determined from both equations which were derived from the stepwise and direct discriminant function analysis. Each dimension was multiplied with its associated unstandardized coefficient and adding the products together along with the constant, a score was calculated, If the discriminant score is more than the sectioning point which we determined from the discriminant score equation, then it indicates a male skull, whereas, a value lower than sectioning point indicates a female skull. The tested accuracy of sex determination of the skull by stepwise discriminant function analysis was 72% and by direct discriminant function analysis was 75%. In the present study the percentage of correctly classified skulls was quite low, with direct discriminant function providing slightly better results than stepwise discriminant score equations.

Discussion

Gender determination in forensic sciences helps to channelize the investigations by deducing the search to half the population, thus conserving both resources and the time required for identification. The FM is a vital and prominent structure of the skull base, the dimensions of which are influenced by genetics, environment, and social factors. [10] Taking this into account, we conducted the present study on the North‑Western (N‑W) Indian subpopulation of Indore. In the literature, many authors have showed sexual dimorphism in the dimensions of FM among different Indian sub‑populations, but they have used dry skulls to derive their results. This limits the study sample. Also, archiving skulls of known age and gender for a study is an added drawback.

The FM measurements in our study showed statistically significant ($p < 0.05$) differences between the gender with all values significantly greater in males than females except LD which was noted slightly higher among females (36.9 ± 3.51 mm). Babu *et al.* [11] found the mean LD values to be 40.86 mm in males and 39.75 mm in females, whereas Kanchan *et al.* [12] reported values of 41.15 mm in males and 40.3 mm in females. This difference of result can be because of different populations studied, different study method.

In the present study, the area of FM among both genders (male = 944.12 ± 164.64 mm2 and female = 902.16 ± 90.21 mm2) was found comparable to Kanchan *et al.* and Babu *et al.* [12] studies with statistically significant gender difference. The FM area was calculated by using Radinsky's formula as in a review of literature also, researchers had used two formulae to calculate the FM area, Texeira formula, and Radinsky's formula. Among the studies conducted in the Indian population, the value for area obtained by Radinsky's formula is a better evaluator of sex.

A significant statistical difference regarding FM circumference (male = 99.62 ± 6.44 mm and female = 96.51 ± 12.94 mm) was found in the present study, the results are following Raikar *et al..*, [13] studies where the mean C values were male = 127.51 mm; female = 119.59 mm and male = 119.6; female = 110.3 mm respectively. The FI was calculated (if FI ≥ 1.3) which helps us in determining the shape of FM when values of circumference and area cannot be assessed.

In the present study, the most common morphological FM shape was found to be Egg shape (27%) in both genders, whereas the least common shape was round (no case) in females and hexagon and round (4%) in males. Raikar *et al.* [13], observed similar findings. But according to Holland *et al.* the incidence rate of round shape was most common followed by egg and tetragonal. This difference among the results of studies might result from racial differences or visualization techniques.

The strong interobserver correlation in our study implies that FM dimensions are minimally affected by subjective variations and hence are highly reproducible in determining sexual dimorphism. It was seen that FM dimensions tested using digital SMV were 69.73% accurate in differentiating sex and 82.29% and 85.45% in male and female determination, respectively. The results were following the Gapert *et al.* [15] (82.1%), Texeira *et al.* (80%), and Suazo *et al.* [16] (78.2%). However, the accuracy achieved by Uysal *et al.* [17] in their studies on a sexual determination by FM using CT was found to be 85%.

It is evident from the results that males displayed larger mean values than females for all measured variables of the foramen magnum. Of all the variables only one variable i.e., Maximum Bicondylar Breadth (BCB) exhibited statistically significant difference between the sexes. Although length and width of foramen magnum was found to be slightly larger in males than females in the present sample, these dimensions did not yield statistically significant differences.

However, in French sample the length of foramen magnum did not reveal significant differences but width showed the significant results. In African – American group (Wescott & Morre Jansen, 2000) [18] found length of foramen magnum as one of the most reliable measurements for sex determination. Our findings are in contrast with the results reported on British sample (Gapert *et al*., 2009), [15] UNIFESP sample (Suazo *et al*., 2009) [19] as well as on Indian populations which show statistically significant differences between males and females for length and breadth. In our study the mean of foramen magnum area in females was found to be smaller than in males. This result is in consensus with the findings reported by Suazo *et al*., 2009 [19]. Morphometric analysis of foramen magnum for sex determination: Singh & Talwar (2013) al., (2009) [20] and Macaluso Jr. (2011). [21] Our study did not reveal significant differences for mean of foramen magnum area. This finding is in contrast with those reported by Singh & Talwar (2013) al., (2009). [20]

Maximum Bicondylar Breadth (BCB) exhibited significant differences between skull of males and females in the present sample. Similar findings have been reported from other studies where intercondylar dimension i.e., Maximum Bicondylar Breadth (BCB) displayed significant difference in diverse populations including the historic British samples from St. Bride's church. In the present study, the values of maximum bicondylar breadth (BCB) as observed in both sexes (males 52.37mm; females 50.92mm) were comparatively smaller than French skulls (males 61.23mm; females 59.37mm) British samples (males 61.92mm; females 57.76mm) and African– American group (Black males 49.6mm; females 55.6mm; white males 61.3mm; females 59.4mm). Besides BCB, Gapert *et al.* (2009) [15] in the British sample, found MxID and EHC to be significantly dimorphic, which was not the case in the present study. In our study maximum bicondylar breadth was found to be the most reliable variable for sex estimation.

It is widely recognized however, that size related levels of sexual dimorphism are generally population specific, due to a combination of genetic, environmental and socio-cultural factors and thus metric standards developed for sexing cranial remains may not be accurately applied to other skeletal samples (Kajanoja 1966). [22] It can be concluded from the present study that of, all the variables considered in the present study, maximum bicondylar breadth was found to be the most reliable variable for sex estimation. In stepwise, analysis it was found to be more discriminating variable providing an accuracy of 72%. The accuracy of sex prediction base on discriminant function analysis ranged from 72% to 75%. Looking at the overall accuracy rates in the present study it can be inferred

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that morphometric analysis of foramen magnum dimensions cannot be regarded as a very reliable method for determining sex in the present collection on complete skulls.

However, in case of highly fragmentary remains, where no other skeletal remains are preserved, metric analysis of the basal region of the occipital bone may provide a statistically useful indication as to the sex of an unknown skull. (Gapert *et al*.,2009). [15] Similar findings have been reported by present study. Since the present study was based on a limited sample, it is suggested that further research based on larger samples of documented Indian skulls should be undertaken to check the reliability of morphometric measurements of foramen magnum in sex determination.

Limitations and future prospects

Limitations of the present study include a small study sample that cannot give accurate supportive evidence to the results got so far, a bigger sample size would easily substantiate the results got in our study. There can be errors in the identification of shapes of FM due to difference in the visualization by the observers.

Conclusion

The study recommends the use of SMV radiographs in elucidating FM morphometric variations for the identification of unknown individuals and may act as a guide to the anatomists, neurosurgeons, and in other medical fields as well. These findings would be interrogated as reliable indicators in sex determination of unknown skulls. Data should be only used as a corroborative finding in predicting sex in case of fragmented cranial bases and not recommended as sole indicators for sexing complete skulls. More research on wider scale of adult population is warranted to validate such specific discriminatory functions, estimate their classification accuracy and to update them periodically so as to avoid human secular trends among populations.

The present study indicates significant sexual dimorphism exist in these parameters. These parameters should be taken into consideration during craniovertebral and cervical spine surgical procedures. Morphometric analysis of foramen magnum can be used as supportive findings in estimation of sex of fragmented, incomplete or damaged dry human skulls. The knowledge of morphology and morphometry of foramen magnum is important for neurosurgeons, radiologists as well as anthropologists.

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